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Issues Associated with Telerobotic Systems in Space

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ABSTRACT

This paper presents the research issues in using telerobotics in space. Included in this paper is a review of previous research in space telerobotics and the results of several telerobotics experiments.

INTRODUCTION

A number of studies have been conducted beginning in the 1970's concerning the issues associated with telerobotic systems. Some of the research issues in telerobotic systems for space application are: video viewing, scene lighting, feedback delays, and predictive displays.

Video Viewing

Three camera locations are commonly considered in most research studies. The first camera is mounted on the manipulator and gives a close up view directly over the robotic gripper. A second camera provides an overall view or scene of the task area. This camera provides depth perception to the operator. A third camera may also be necessary to provide an overhead view of the task area.

Several previous camera studies [Pennington 1983] have concluded that operators prefer two views. One view is positioning the camera for a side view, or orthogonal to the task board, and above the center of the board with a 60 degree field of view. The second view is positioning the camera above the task area and viewing down at a 70 degree angle.

A related issue in video viewing is the use of black and white versus color cameras. Most researchers have used a black and white camera on the manipulator and a color scene camera [Collins 1986]. The research has concluded that black and white cameras are adequate [Yorchak 1986].

Several studies have also been conducted concerning the use of stereo cameras. A dexterity test consisting of the peg-in-hole task with various size pegs concluded that the smaller pegs required more time than the larger pegs [Brye 1977]. Also, the response time was considerably less for a stereo camera system as compared to an orthogonal monoptic system.

In summary, an evaluation of a number of recent video viewing studies [Yorchak 1986] concluded that two cameras are better than one, two cameras positioned orthogonally are better than two cameras positioned to produce stereo, and a third camera for an overhead view does not seem necessary.

Scene Lighting

Since all space telerobotic tasks are performed in space, scene lighting is a critical factor. For example, a task can go from total darkness to total brightness by a mere change in orientation. Likewise, it is possible to obtain a variety of shadow conditions based on the location and position of the robot and the task in space. Scene lighting is relatively easy to simulate in a laboratory. For example, in the laboratory flat black drapes can completely surround the facility. Also, black cloths can be placed on the floor and around the task boards to eliminate any reflections. The overhead lights are then extinguished. The source lighting can then be directed at various intensities and focused on the task. In addition, a variety of shadows can be displayed on the task by positioning the light sources accordingly.

Feedback Delays

Time delays are inherent in any teleoperation system. Sending and receiving transmissions from space or space vehicles can result in time delays between 0.5 and 8.0 seconds. The length of delay depends on the number of switching satellites and the data processing times. A number of studies have been made of the effect of time delays on operator performances. In general, these studies have concluded that the task time increases with an increase in time delays [Ferrell 1965].

A related issue to time delays is the effect of limited camera bandwidths on operator performance. Bandwidths are generally limited because of the vast amount of data transmission necessary between the manipulator and the control station. Several studies [Ranadive 1979 and Deghuee 1980] have concluded that the operator can perform familiar simple tasks with considerably reduced bandwidths; however, these studies were done without any time delays.

Predictive Displays

Time delays cannot be completely eliminated in any teleoperation system. However, with predictive displays the operator is able to see, via a computer graphics representation of the robotic area, exactly where the robot will be after the commands are executed. As the operator moves the arm, the model will, in real time, update the graphics display to show the operator the effects of the command before the arm has actually received the command. This type of predictive feedback is useful to the operator by improving the low productivity of move and wait tactics. For example, a recent study [Sheridan 1984] found that predictive displays reduce task time between 50-150 percent. Also, in another study [Arnold 1963] predictive displays enabled the operator of a remote vehicle to drive at the same speed nearly as well with or without a time delay.

ROBOTICS LABORATORY

Figure 1 presents a system schematic of the space telerobotics laboratory at the University. The laboratory is configured around a Puma 562 6 DOF arm. Mounted on the arm is a high resolution black and white CCD camera (see Figure 2). The Puma is remotely controlled with two 3 DOF hand controllers at the control console.

Several scene cameras are located around the task board. One of the cameras is a color camera with auto white balance and a zoom lens that is mounted on a pan and tilt unit. Both the zoom lens and the pan and tilt unit are remotely controlled at the control console. The second scene camera is a black and white camera. All video output is fed back to monitors at the remote control console.

The inter-meshing gripper is a modification of a NASA design [NASA 1980]. The gripper is electrically operated and has two limit switches to indicate when the gripper is fully open or closed. The gripper is remotely controlled at the control console.

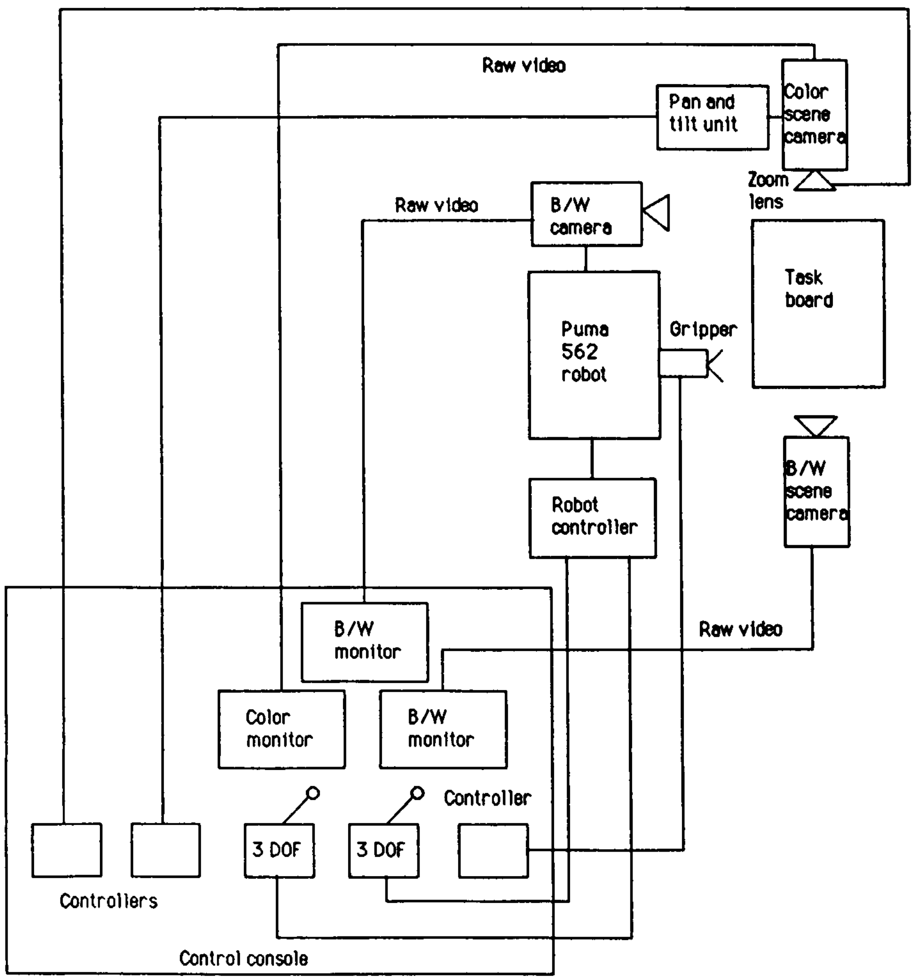

Figure 1. System schematic of robotics laboratory

TELEROBOTIC EXPERIMENTS

A simple peg-in-the-hole task was defined to evaluate the laboratory's hardware and software, especially the Puma control software. In addition, by selecting the peg-in-the-hole task, it was possible to compare and validate the results with previously published research. Figure 2 also includes a photograph of the peg-in-the-hole task board. Each board consists of three 1 1/8 inch holes. The peg diameter is one inch. Initially,

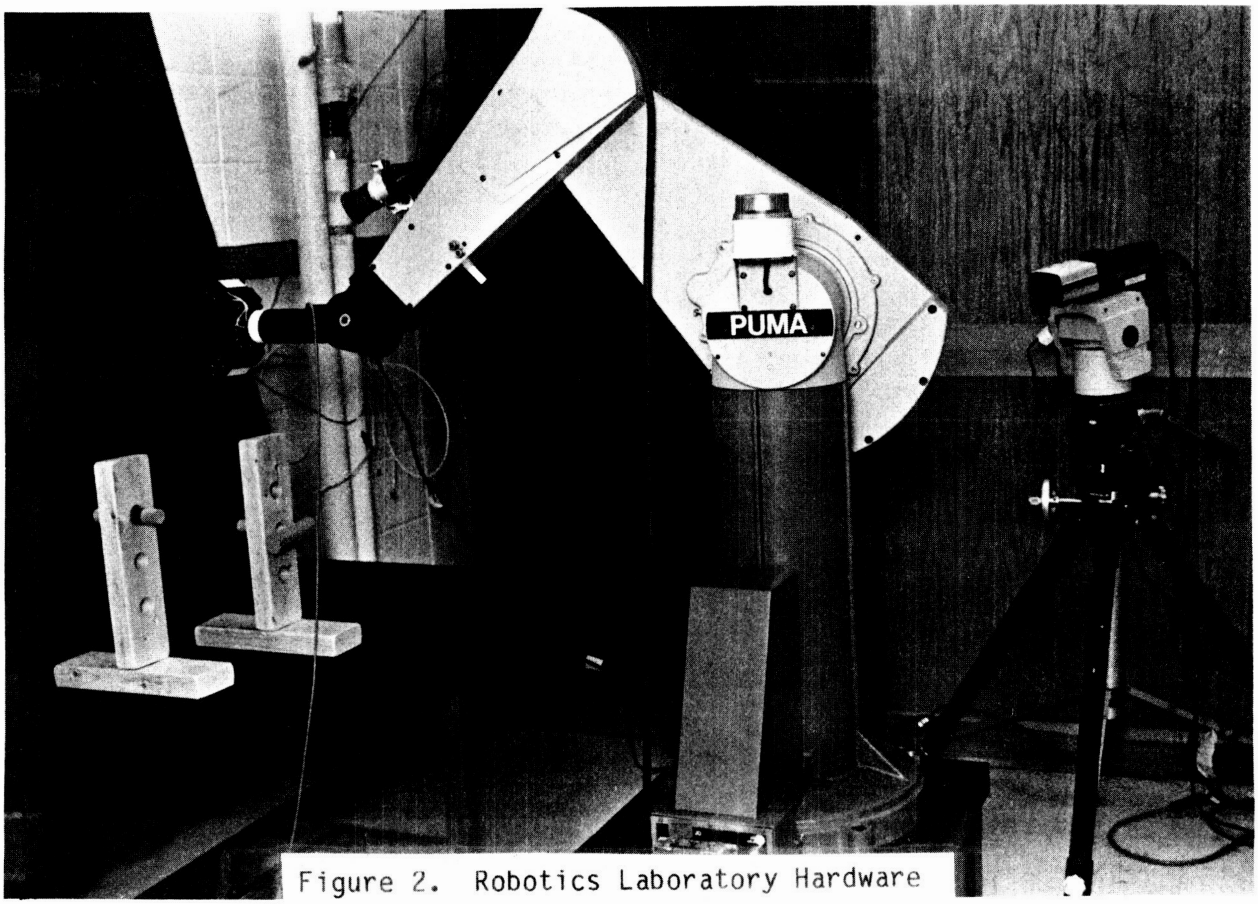

Figure 2. Robotics Laboratory Hardware

the peg is in the top hole on the right board. The task objective is to transfer the peg to the bottom hole on the left board. The response variable is the time to perform the task. This response variable is common to most telerobotic experiments. The scene lighting equipment did not arrive in time for the experiments. Therefore, all experiments were conducted with the normal laboratory lights turned on.

The following factors and levels within factors were considered in this experiment:

- Factor 1 - Time delay.
  Three levels of time delays were used (0, 1, and 2 seconds). These delays were changed through the robot control program.

- Factor 2 - Camera view.
  Three levels of camera views were used with each level consisting of two cameras: a side scene view and and an arm view where the camera was mounted on the Puma arm; an angle scene view with pan/tilt/zoom and an arm view; and an angle scene view with no pan/tilt/zoom and an arm view.

- Factor 3 - View color.
  Two levels were used: black and white and color. Only the side view camera with the pan/tilt/zoom was color.

Each level of each factor is combined with all levels of every other factor in the experimental design. Therefore, the experimental design consists of a 3x3x2 completely randomized factorial experiment. This design results in 18 cell. Each cell is also replicated four times, two each by two student subjects, for a total of 72 runs.

The ANOVA results show a significant effect of time delay on task time ($F = 33.18$, $p<0.05$). A number of other research studies have been made on the effect of time delays on operator performance. In general, these studies have concluded that the task time increases with an increase in time delays [Ferrell 1965 and Yorchak 1986].

The ANOVA results did not show a significant effect of camera view on task time ($F = 1.80$). While the camera view did not show a significance, the subjects stated preference for the side, or orthogonal, view as opposed to the angle view. This preference agrees with findings by Kirkpatrick [Kirkpatrick 1973] that orthogonal views are more effective.

The ANOVA results did not show a significant effect of view color on task time ($F = 2.31$). This result agrees with other researchers who have concluded that black and white cameras are adequate [Yorchak 1986]. The ANOVA results also did not show any second or third order interaction effects. These four interactions were delay and view; delay and color; view and color; and delay, view and color.

Figure 3 is a plot of the total task time for the 0, 1, and 2 second time delays. The task times were averaged for each time delay and represent 24 values. As can be seen, the total task time increased from 2.99 seconds with 0 second delay to 4.64 seconds with a two second delay.

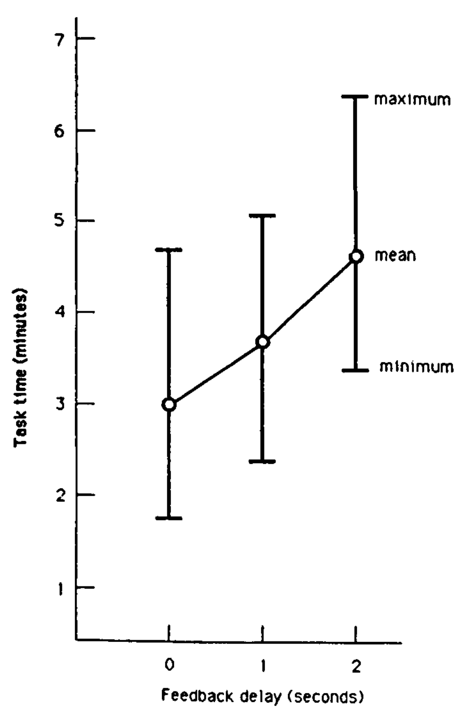

Figure 3 . Total task time with feedback delays

CONCLUSIONS

Future enhancements to the laboratory include: placing the pan/tilt/zoom under voice control, predictive displays and artificial intelligence as an operator assistant. Additional experimentation will include increased sample size, increased task difficulty, and improved task boards and lighting. This experimentation will produce data to answer questions proposed by previously research and will provide information on telerobotics for space applications.

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